Propulsion

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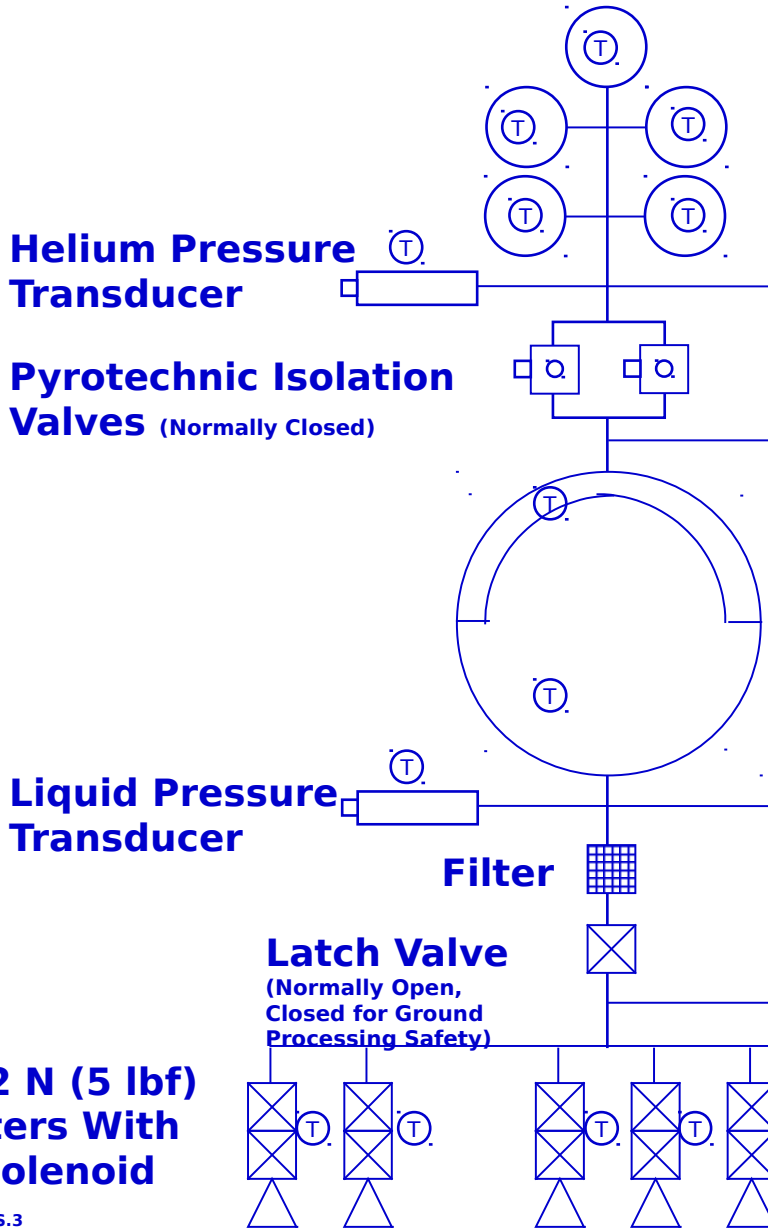
Propulsion Mission Requirements

- Provide Thrust for Spacecraft Orbit Raising, Attitude Control, and Stationkeeping
- Provide Single Critical Fault (Credible) Tolerant Propulsion Design or Graceful Performance Degradation
  - Pressure Activation via Ordnance
  - Thruster Failure Results in Degraded Mission
  - Valve Leakage via Dual Seat Thruster Valves and System Latch Valve
- 5 Year Mission Life
  - Design for Delivery by June 2003
    - Derived From Integrated Master Schedule
  - Design, Qualify, and Test for FAME Mission and Launch Environments
    - NCST-TP-FM001, FAME Test Plan
    - New or Re-Designed Systems Will Have Protoflight Testing
- Meet Launch Base Safety Requirements and Verification Process
  - EWR-127-1 1999 Version With 2000 Change Pages, Tailored for FAME
- Support Science Mission Requirements
  - Minimize CG Migration, Plume Contamination, and Minimum Impulse Bit
  - Provide Most Flexible Design While Minimizing Cost and Schedule Risk

FAME Propulsion Schematic



5 Tank Pressure Manifold for Helium Storage

Helium Pressure Transducer

Helium Tank Service Valve

Pyrotechnic Isolation Valves (Normally Closed)

Hydrazine Tank Gas Service Valve

Off-the-Shelf Near Sphere Hydrazine Tank With Metallic Diaphragm (PMD)

Liquid Pressure Transducer

Hydrazine Tank Liquid Service Valve

Filter

Latch Valve
(Normally Open, Closed for Ground Processing Safety)

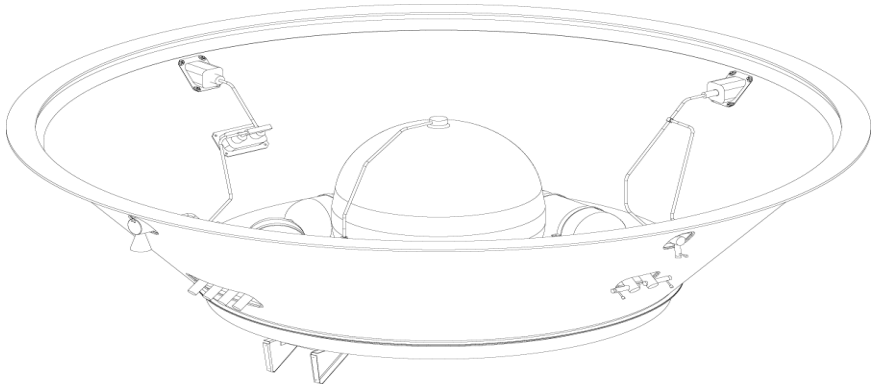
Test Service Valve and Low Point Drain

Two 22 N (5 lbf) Thrusters With Dual Solenoid Valves

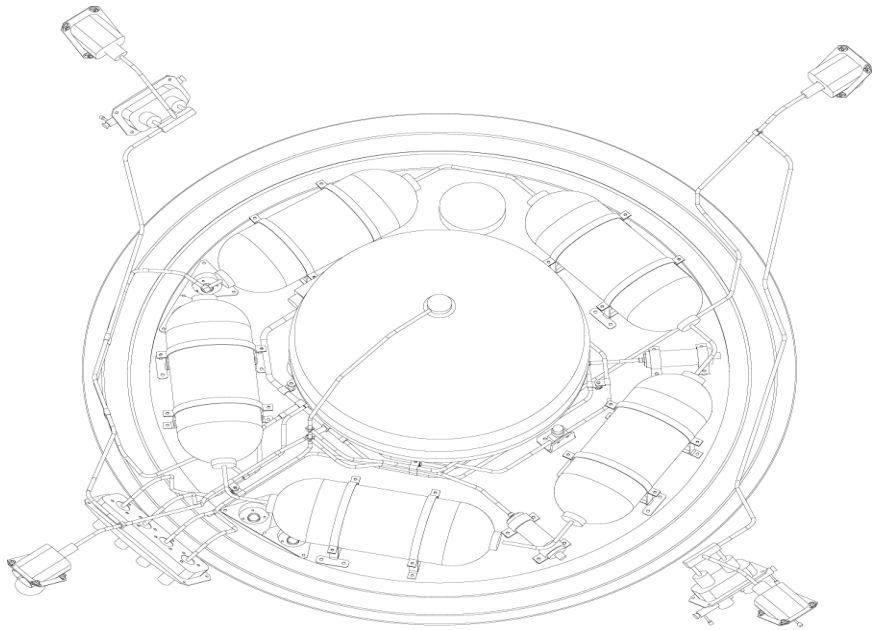
Six 1N (0.2 lbf) Thrusters With Dual Solenoid Valves

Propulsion Packaging Design

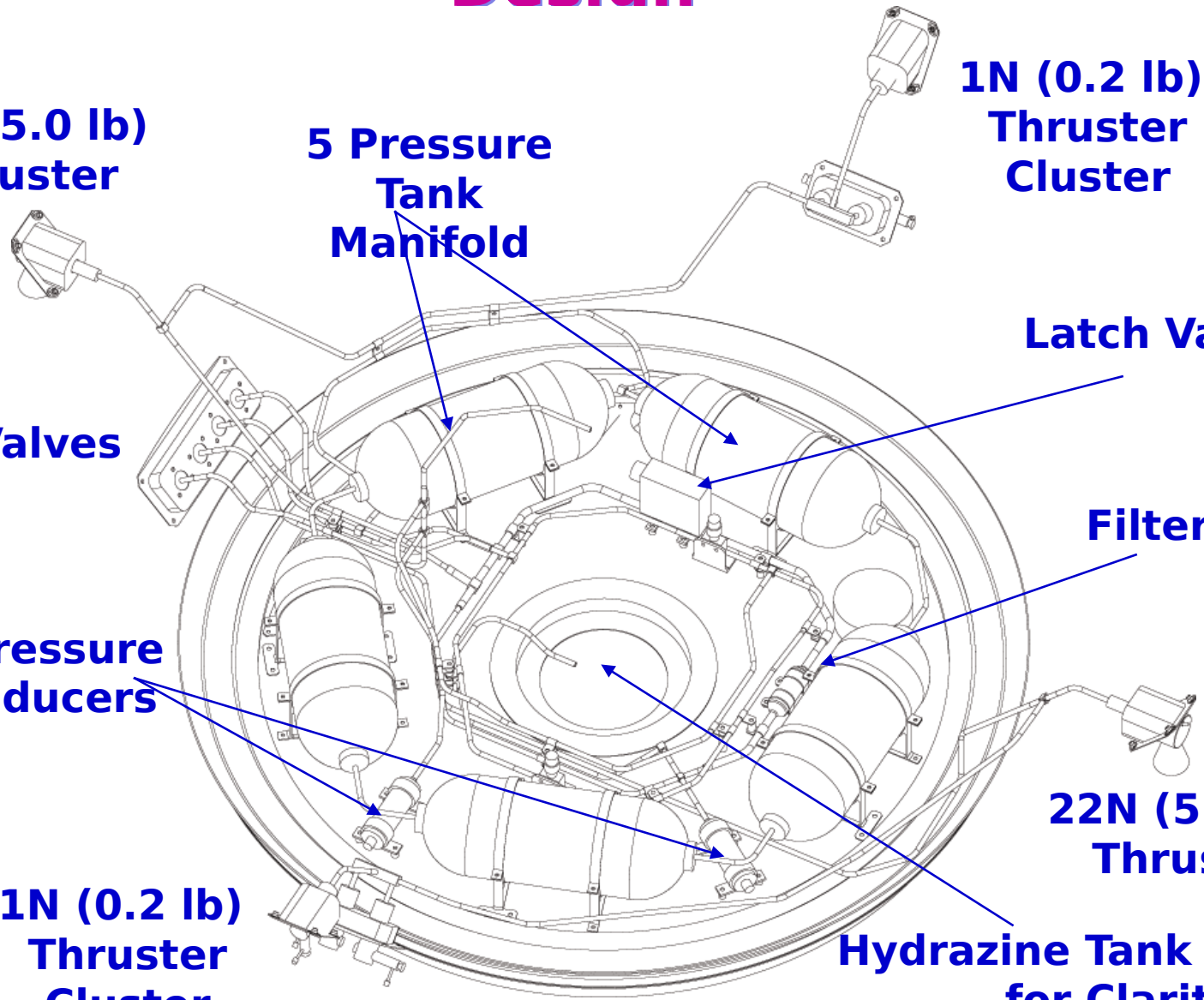
- **Propulsion Deck Integrated to Bus Conical Structure**



- **Propulsion Deck and Plumbing to Thrusters**



Propulsion Packaging Design



Propulsion Baseline Design

- One Centrally Located Off-the-Shelf Monopropellant Hydrazine Tank
  - Contains a Metallic Propellant Management Device (PMD) for Slosh Mitigation and CG Control Knowledge
  - Mass, Cost and Schedule Constrained Implementation Is Not Optimal Due to Limited Tank Availability - Too Big, Too Small, or Elastomeric Diaphragm
- 5 Pressure Bottles Supply Blowdown Pressurization (Nominal 4:1)
- Two Pressure Transducers Provide Gas and Liquid Pressure Telemetry Data
  - Propellant Usage and Prediction of Thruster Performance
- 8 Total Hydrazine Thrusters for and Attitude Control, Vehicle Delta V, Spin, Active Nutation Control (ANC)
    - Two 22N (5.0 lbf) Thrusters (Active Nutation Control, Delta V)
    - Six 1N (0.2 lbf) Thrusters (3-Axis Control, Slew, and Spin)
    - Refurbish In-House Existing Thrusters
  - Series Thruster Valves (Leakage Protection)
  - Each Thruster Has a Valve Heater, Temperature Sensor, and Catalyst Bed Heater
- ICM Flight Spare Latch Valve Provides Leakage Tolerance and Personnel Protection
  - Normally Open for Flight, Closed for Ground Safety (3rd Mechanical Fault)
- Four Fill Valves for Pressure Loading, Propellant Loading and System Check-Out
- Pyrotechnic Isolation Valves Between the Helium Bottles and Hydrazine Tank
- Thiokol STAR 30BP Apogee Kick Motor (AKM) With Rented or Modified GSE

Propulsion Trades Completed - Solid Upper Stage and Hydrazine

- Other Propellant Systems Considered to Perform the FAME Mission Include:
  - Solid AKM and Cold or Warm Gas Systems
  - All Electric Propulsion Upper Stage
  - Solid AKM, Cold Gas, and Electric Propulsion
  - Separable Bi-Propellant Upper Stage (MMH/NTO/N2H4)
  - Non-Separable Bi-Propellant Upper Stage (NTO/N2H4)
- Solid Apogee Kick Motor (AKM) and Monopropellant Hydrazine Propulsion System Selected for FAME Mission Orbit Insertion
  - Solid Rocket Motor Trades
    - STAR 37S, STAR 37XFP, STAR 37XFP Modified Case, STAR 37XFP-TIROS, STAR 30BP, STAR 30C, Electronic Safe and Arm Device
  - Hydrazine Tank Trades
    - 22” Elastomeric Diaphragm, Custom Metal Diaphragm, 31” Metal Diaphragm, CLEMENTINE Metal Diaphragm, ARDE Metal Diaphragm
  - Thruster Trades
    - Quantities of 8 to 12 With Various Numbers of 22N, 4N, and 1N Thrusters
    - New and Re-Furbished In-House Thrusters
  - Pressurization Trades
    - Single Tank Blowdown, Augmented Blowdown, Active Pressure Regulation Control, Multiple Re-Pressurization

Propulsion Analysis

- Delta 7425-10 Launch Vehicle
  - Determined Throw Weight and Margin to FAME Injection Orbit
  - Analysis Based on Current Masses
  - Evaluated Injection Errors
- STAR 30BP AKM
  - Determine Margins and Offload Requirements
  - Evaluate Total Impulse and Pointing Errors
- On-Board Hydrazine System
  - Propellant Selection and System Sizing
    - Thruster Performance
  - Propellant Analysis Including Margins Analysis
    - Orbit Insertion Error Contingency Plan
    - Propellant Allocations
  - Propellant Tank Sizing and Selection
  - Pressurization System Sizing and Selection

Propellant Budget

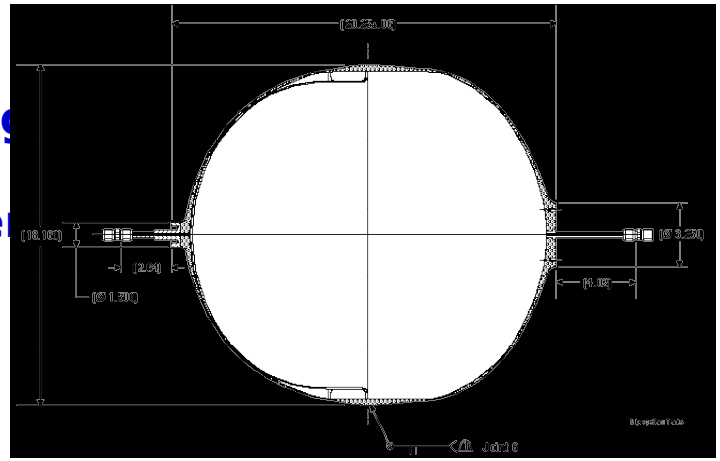
Event	Event Description	Delta V (m/s)	Ave Isp (sec)	Initial Gas Pressure (psia)	Ave Thrust (N)	Initial Mass (kg)	Delta V Prop (kg)	ACS Prop (kg)	Prop Remaining (kg)	Burn Time (sec)
0									49.9	
1	Null Delta 3rd Stage Tip Off		160	350.0	1.26	1110.0		0.10	49.8	124
2	Inertial Pointing (3-axis limit cycle)		160	348.4	1.24	1109.9		0.14	49.6	182
3	Slew Manuevers		160	346.2	1.19	1109.8		0.40	49.2	528
4	Safe Hold Mode Spin up/down		160	340.0	2.35	1109.4		0.06	49.2	42
5	GTO Perigee Correction	0.60	220	339.1	47	1109.3	0.31	0.00	48.9	14
6	GTO Apogee Correction	9.14	220	334.5	45	1109.0	4.69	0.06	44.1	228
7	Spin-up FAME with SRM		220	339.1	2.29	1109.3		1.36	42.8	1282
8	Active Nutation Control		160	323.2	21.91	1107.9		6.52	36.2	467
9	Spin Axis Precession (6 degrees)		160	264.0	20.43	1101.4		0.27	36.0	21
10	STAR 30BP Firing		290	262.1	26999	1101.1			36.0	55
11	Active Nutation Control		160	262.1	20.03	663.1		1.84	34.1	144
12	Despin FAME with Spent STAR 30BP		220	249.3	1.69	661.3		1.11	33.0	1410
13	Slew Manuevers		160	242.2	0.83	660.2		0.58	32.4	1091
14	Inertial Pointing (3-axis limit cycle)		160	238.7	0.79	659.6		3.37	29.1	6713
15	Disposal Orbit Trim Manuever	16.93	220	219.9	34.25	656.2	5.13	0.07	23.9	327
16	Jetison STAR 30BP and Adaptor	0.5	220	196.1	32.57	651.0	0.15	0.00	23.7	10
17	Orbit Trim Apogee	0.25	220	195.4	32.51	556.5	0.06	0.00	23.7	4
18	Orbit Trim Perigee	10.06	220	195.2	31.77	556.4	2.59	0.04	21.0	178
19	Slew Manuevers		160	185.1	0.62	553.8		0.27	20.8	690
20	Phasing Manuever	18.28	220	184.1	29.72	553.5	4.67	0.07	16.0	344
21	Phasing Manuever Correction	0.16	220	168.5	28.20	548.8	0.04	0.00	16.0	3
22	Inertial Pointing (3-axis limit cycle)		160	168.3	0.54	548.7		1.07	14.9	3114
23	Safe Hold Mode spin up/down		160	165.2	1.02	547.7		0.71	14.2	1090
24	Raise Apogee to Disposal Orbit	5.44	220	163.2	24.93	547.0	1.38	0.02	12.8	121
25	Raise perigee to Disposal Orbit	5.44	220	159.3	23.44	545.6	1.37	0.02	11.4	128
26	5% Unusable Residual		160	155.6	0.82	544.2	2.49		8.9	4791
27	Fuel Margin		160	149.5	18.55	541.7	8.91		0.0	753
	Total	**66.80**					**31.80**	**18.08**		

49.9 Kg (110 lb) Propellant Load With 21.7% Margin

In-House Flight Hardware

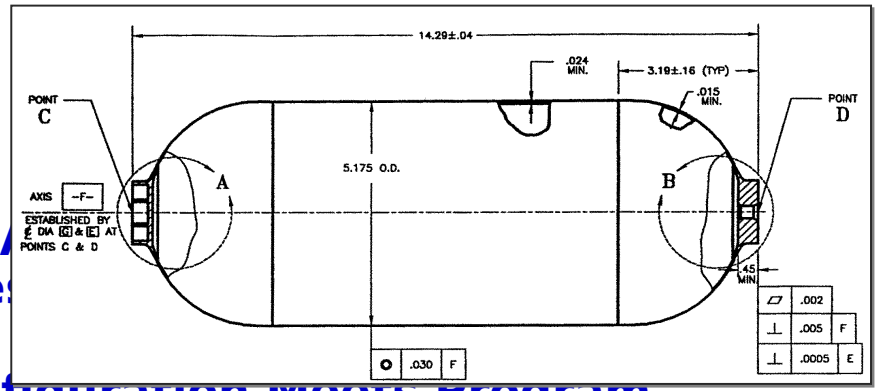
ARC Metal Diaphragm Tank

- Developed and Qualified for the NRL CLEMENTINE Program
- Atlantic Research Corporation (ARC) P/N AO882300
  - 19 x 21 Inch Elongated Sphere (3125 Cubic In)
- CLEMENTINE Maximum Expected Operating Pressure (MEOP) 300 psia, Proof 450 psia
- FAME MEOP 400 (TBR) psia, Proof 500 TBR psia
- Minimum Design Burst 650 psia
  - Polar Inlet and Outlet Tubes
    - FAME Will Modify to 90 Degree Tubes, No Qualification Impact
  - Tank Weight 7.62 kg (16.8 lb)
  - Polar Boss Mounted
  - AL 2219 Shell, AL 1100 Metal Diaphrag
- Requires Secondary Pressurization Syste
  - Fill Tank to 97% With Hydrazine
  - 110 lb Hydrazine Maximum Capacity



ARDE Pressurization Tanks

- 5 Pressure Tanks Required for Single Blowdown Operation
- ARDE, Inc Tank Number 4051
  - 5.2 x 14.3 Inch Cylinder (Outside Diameter) (240 Cubic In)
- FAME Maximum Expected Operating Pressure (MEOP) 400 psia
  - Design MEOP of 1050 psig, Design Proof 1575 psig, Minimum Burst 2100 psig, Demonstrated Burst 2570 psig
  - Polar Inlet and Outlet Boss With Threaded Female MS Connection
  - Tank Weight 0.916 kg (2.02 lb)
  - Cradle and Band Clamp Mount
  - All Metal Construction
- Developed and Qualified for As NASA Astronaut Space Suit Oxygen Bottles
- An All Welded Tube Stub Outlet Configuration Meets Program Reliability, Schedule, and Cost Constraints
- Alternative Pressure Tank Options are Under Investigation

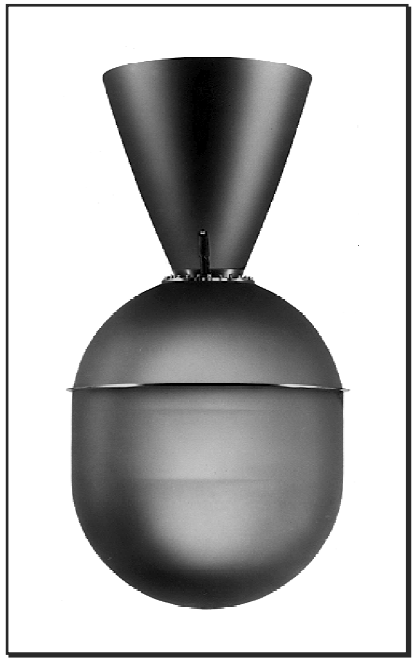


Hydrazine Thrusters

- Hamilton Standard REA 16-9, 22N (5 lbf)
  - Expansion Ratio 60:1
- Hamilton Standard REA 10-16, 1N (0.2 lbf)
  - Expansion Ratio 55:1
- In Stock at NRL From Previous Programs
  - Fully Flight Qualified for NTS, MSD, and CLEMENTINE
  - Single Seat Valve Originally Included to Be Replaced With Dual Seat Valve For Protection Against Leakage
    - Clementine Mission Flew Two Similar Thrusters With Dual Valves
    - Maximum Inlet Pressure 300 psia
    - Proof 600 psid
    - Burst 1200 Ppsid Minimum
- Steady State Specific Impulse of 220 Isp
- Pulse Mode Specific Impulse (20ms Min Pulse) 200 Isp (Hot Bed)
- Pulse Mode Specific Impulse (20ms) 160 Isp (Cold Bed)

Solid Rocket Motor (SRM) for GEO Insertion

- Alliant TechSystems (Thiokol) STAR 30 BP Solid Rocket Motor
  - Hughes HS-376 AKM
  - > 60 STAR 30 Series Flights
  - TI 6AL-4V Case
  - Carbon-Carbon Throat With Carbon-Phenolic Nozzle
- Performance
  - Total Impulse 328,200 lb-sec
  - Average Thrust 6070 lb
  - Burn Time 55 sec
  - Effective Specific Impulse 292 sec
  - Spin Capability 40 to 100 rpm
  - Capable of 20% Propellant Offload
- Weights
  - Total Loaded 1196.7 lb
  - Maximum Propellant 1113.6 lb
  - Empty Weight at Burn Out 72.0 lb
- Delta 7425 Maximum Payload Requires 12.5% AKM Propellant Offload



Propulsion Integration and Test

- Propulsion Testing Is Performed at Many Levels
- Engineering Flow Model
  - Flow Testing to Verify Analysis
  - Electronics Brassboard and EGSE Verification
- Protoflight or Qualification Testing As Required for Risk Reduction
- Flight System
  - Vendor Acceptance Test
  - NRL Component Acceptance Test
  - Sub-assembly Acceptance Tests (Some)
  - Stand Alone Integrated Acceptance Test
  - System Integrated Acceptance Test
  - Pre-Environmental Functional Test
  - Post Environmental Acceptance Test
  - Pre-Ship Acceptance Test
  - Arrival Acceptance Test
  - Final Acceptance Test

Ground Support Equipment

- Cleanrooms
  - Class 100 Horizontal Laminar Flow
  - Class 1000 Vertical Turbulent Flow High Bay
- Cleaning Systems and Commodities
  - Ultrasonics
  - Solvent Flushing Equipment
  - Non-Volatile Residue Measurement
  - Automated Liquid and Air Particle Counting Equipment
- Orbital TIG Welding Equipment
- Pressure Testing Panels
- Propellant Service Carts
- Leak Detection Equipment
- Vacuum Carts
- Pressurant Control Console
- Pressure Temperature Monitor Box
- RCS Test Box

Safety

- EWR 127-1 Requirements
  - Some Tailoring Is Required But Design Meets Safety Intent
    - As an Example For Pressure Testing, Replace Most “Hydrostatic” With “Hydrostatic or Pneumatic”
- Design
  - Pressure Factors
  - Material Properties
  - EWR 127-1 and MIL-STD-1522 for Pressure Vessels
  - Turn- On Plug Connectors Ensure Hardware Not Activated
    - RCS Electrical, RCS Ordnance, Solid Rocket Motor, Ordnance and Valve Drive Electronics Signals Grounded Through Separation Switch
- Verification
  - Mechanical and Electrical Testing
    - Pressure and Functional Acceptance Testing
  - Hazard Evaluation, Reporting, and Control
    - Hazardous Operating Procedures

Propulsion Support for Launch Site Operations

- Receive Range Safety Briefing, Required Training and Certification
- Hazardous Operations Procedure Sign-Off
- Receive and Check-Out Propulsion MAGE
- Receive STAR 30BP Solid Rocket Motor (Shipped Directly to KSC)
  - Acceptance Test and Integrate to the Interstage Assembly
- Hydrazine Service Cart Loading
- FAME Propulsion System Check-Out
- FAME Propellant Loading and Pressurization
  - NRL Has SCAPE Trained Personnel and Propellant Loading Equipment
  - KSC Offers Propellant Loading Services
- Spacecraft and Interstage Integration
- FAME Wet Spin Balance Verification
- Final FAME Propulsion Verification
- Transportation to Launch Tower
- Red Tag Item Removal
- Final Safe & Arm Installations and Open and Verify Latch Valve
- Install Fairing

Up-Coming Propulsion Efforts

- Complete System Trades
  - Confirmation Review Support, Final Launch Vehicle Selection, Complete Propellant and Pressurization Trades and Final Propulsion Design
- Hardware Procurements
  - Tank Procurements
    - Complete Specifications, Prepare PPD Packages
  - Thruster Refurbishment
    - Valve Heaters, 1N (0.2 lb) Catalyst Bed Heaters, Thermistors, Testing
- Perform Detailed Propulsion Flow Analysis
  - Steady State for Pressure Drops and Thruster Performance Predictions
  - Transient Analysis for Water Hammer and Surge Pressures
- Complete EWR 127-1 Requirements Review and Tailoring and Generate Hazard Reports
- Complete the Detailed Propulsion Design (Part Level)
- Assemble and Test Propulsion Flow Model
- Prepare Component Acceptance Test and Manufacturing Documentation
- Critical Design Review Preparation

Schedule Milestones

- Propellant Tank Contract 1/1/02- 12/02
- Pressure Tank Contract 1/1/02 - 12/02
- Pressure Transducer Procurement 3/02-10/02
- Propellant Filter Procurement 3/02-10/02
- Thruster Refurbishment 5/02- 9/02
- Critical Design Review 8/02
- Offline Sub-Assembly Fabrication 11/02 - 2/03
- Propulsion Tank to Deck Integration and Test 2/03 - 5/03
- Propulsion to Bus Integration 6/03 - 7/03
- Propulsion Functional Testing 7/03 - 8/03
- Integrated Propulsion Test (Flight Electronics) 11/03 - 12/03
- Test Readiness Review 1/04
- Flight Environmental Testing and Vehicle Check Out 1/04 - 3/04
- SRM Contract (Deliver to Cape) 4/02 - 4/04
- SRM to Interstage I&T 8/04
- Propulsion Range Support 8/04 - 10/04
- Launch 10/04

Issues

- Final Launch Vehicle Selection Defines Final Tank and AKM Designs
  - Delta 7425-10 or Delta 7925-10
- Procurement Schedule
  - Long Lead Components Are Required (Well Before 8/02 CDR)
- Tank Selection and Procurement
  - Tank Deliveries Are 12 Months, Contract Award By 1/15/02
  - Delays in Program Funding Will Impact Propulsion Delivery
- Thruster Selection and Procurement (New Thruster Option)
  - Thrusters Delivery Is 10 Months, Contract Award By 2/15/02
- Science Mission Attitude Control With Propulsion is Not in the Baseline Design (Although Previously Studied)
  - Small Impulse Bit Thruster Control System Additional Costs and Effort
    - 18 Months for Custom Pressure Tank or Pulsed Plasma Thruster
- Reliability of Critical Analyses and Assumptions
  - Basis for Selection and Procurement of SRM, Tank, and Thrusters
- Delta II 7425-10 Additional Throw Capabilities for Lower PCS
  - Re-Size Solid and Liquid Systems

Propulsion Issue Resolution

- Selection of the Delta 7925 Launch Vehicle has Positive System Impacts
- Procure Off-the-Shelf 31” Diameter Metal Diaphragm Propellant Tank
  - More Flexible and Robust Design
    - Allows for System Design Growth and Robust Propellant Margins
    - Alleviates Sensitivity to Possible Analysis Errors
  - Propulsion System Has Lower Design Complexity
    - Higher Reliability and Lower Hardware and Integration Cost
    - Eliminates Pressure Tanks, Pyro Valves, Test Valve
- Allows for System Wide Mass for Cost Trades
- Select Thiokol STAR 37XFP Class Solid Rocket Motor
  - Less Expensive AKM With More Capability and Flight Heritage
  - NRL Owns STAR 37XFP GSE
- Schedule and Cost Relief Allows for Propellant Tank Development
  - Optimize Mass, Expulsion Characteristics, and Thruster Performance
    - Higher Cost Due to Development
- Cost Relief Allows Procurement of New Thruster
  - Lower Labor Cost and Better Parts Traceabilty